Optimizing Secondary Roof Support with the NIOSH Support Technology Optimization Program (STOP)

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ABSTRACT

The decade of the 90's brought an unprecedented increase in the development of innovative technologies to provide more effective and easier to install roof support in underground mines. To facilitate the application of these technologies to improve mine safety, National Institute for Occupational Safety and Health (NIOSH) developed the Support Technology Optimization Program (STOP). STOP is a window's based software program that provides mine operators with a simple and practical tool to make engineering decisions regarding the selection and placement strategy of these various standing roof support technologies. This program includes a complete data base of the support characteristics and loading profiles obtained through safety performance testing of these supports at the NIOSH Safety Structures Testing Laboratory. Support design criteria in the form of the required support load density at a specified convergence can be established from four options: (1) a data base of measured ground reaction data from various mines or ground behavior information inputted by the user, (2) determination of loading requirements based on a detached roof block or rock failure height, or (3) criteria based on the current roof support system, and (4) arbitrary criteria set the by user. Using these design criteria, the program will determine the installation requirements for a particular support technology that will provide the necessary support load density and convergence control. Optimization routines are also available to determine the most efficient support design for a user specified support installation. In addition to these performance measures, STOP can be used to compare material handling requirements and installation costs. Comparisons among the various support technologies are easily made including graphical analysis of relevant support parameters. This paper describes the STOP and its application to optimize standing secondary roof support systems.

INTRODUCTION

Secondary support provides additional roof support in the event of failure of the primary support system. When properly designed, secondary support will also assist the primary support in controlling the integrity of the immediate roof beam. Hence, roof support should be thought of as a three-part system: (1) the remaining coal pillars which provide control of the overburden weighting; (2) the primary support system consisting of the roof bolts which help to form a more competent roof beam and in the case of mechanical bolts attach the immediate roof beam in suspension to the more stable main roof rock, and (3) the secondary roof support system which consists of standing roof support and intrinsic support elements that are designed to control the deformation of the immediate roof and handle the additional abutment loading in retreat mining, such as longwall mining where the tailgate is frequently supported with various secondary roof support systems. It should be noted that the STOP in its present form is limited to the evaluation of standing roof support systems.

Engineering design is applied primarily to size the pillars to account for load variations due to depth of cover, active mining zones, and the quality of the roof rock. Computer programs such ALPS and ARMPS are valuable tools in designing pillars for various mining scenarios (*1, 2*). There is no universally accepted

design criteria for primary support (roof bolts), although recent research by National Institute for Occupational Safety and Health (NIOSH) indicates that there may be some fundamental criteria to define conditions where current primary support densities are inadequate. The Wood Crib Performance Model (3) was developed in 1994 to provide engineering design for conventional wood cribs, which were the dominant form of secondary support at the time. The Wood Crib Performance Model determined the supporting capability of various conventional wood crib configurations and matched this capability to user-defined load and convergence criteria. More recently, a design methodology for standing secondary roof support in longwall tailgate applications was developed, which incorporates measured ground reaction data into the formulation of the load and convergence design criteria for standing roof support systems (4, 5).

In the past 5 years, there have been 16 new standing roof support systems developed for use as secondary roof support. These new support systems not only provide superior roof support, but many provide material handling advantages as well. The Support Technology Optimization Program (STOP) was developed by NIOSH to allow mine operators to compare these various support systems and to optimize the application of both new standing roof support technologies as well as conventional wood and concrete crib support systems. Although STOP can be considered as an upgrade of the original Wood Crib Performance Model, it is built on a windows-based architecture and has several enhanced features that were not available in the previous Wood Crib Performance Model. These include: (1) selection from a data base of currently available standing roof support systems for evaluation, (2) synopsis of pertinent design and installation criteria for each support system, (3) description of the performance characteristics including photographs of the support loading profile showing the condition of the support as it deforms, (4) name and phone numbers for the support manufacturers, (5) ground reaction curve support design criteria where the laboratory support performance can be matched to a curve corresponding to the ground behavior as opposed to a single (load and convergence) data point as was done in the wood crib model, (6) enhanced optimization algorithms that determine the support design which is most efficient for the user-specified support installation requirements, or the installation requirements for user-defined support load density and convergence requirements, (7) material handling and cost information for each support, and (8) graphical displays of the support system capability.

It is important to understand that although there are now a wide variety of support choices, each of these support systems have a unique performance profile. Simply replacing one support system with another will not provide equivalent ground control. Most of the new support technologies provide superior supporting capability, which may allow wider spacings of the support to be used if the goal is to provide equivalent support capability to that of a conventional wood crib support system. STOP will determine the spacing requirements that will provide equivalent support capacity. This is one way that STOP can optimize the use of a particular support system. STOP can also provide important information regarding the benefits of increasing the support load density. Using measured ground reaction data, STOP will determine: either the convergence that can be expected from a certain support design installed on a user-selected spacing, or the support spacing required to limit the convergence to a certain level.

This information can be very useful when petitioning Mine Safety and Health Administration (MSHA) for approval to use an alternative support technology. Without this information, MSHA will typically require a trial section where the alternative support system can be observed before full approval is granted. In longwall mining, this means that one might have to wait for a full panel of mining before implementing a new support technology. Likewise, variations in the placement strategy or implementing a change in support design can be delayed until a trial section is observed without an engineering basis to justify such a change. Hence, STOP can be included as another part of the overall process that MSHA may utilize in approving a roof support plan. While it may not be the sole deciding factor, it can provide critical engineering data that will facilitate a decision regarding the implementation of these new support technologies.

This paper will introduce the STOP, describe the architecture of the program, and provide several examples of how it can be used to optimize the design and use of secondary roof support technologies. STOP can provide an engineering foundation to ensure that inadequate support designs as well as ultra conservative support applications are avoided. Safety will be improved by proper matching of the support performance to the mine conditions which will reduce the likelihood of roof falls and blocked escapeways. Material handling injuries associated with support construction are known to account for about 5,000 lost work days per year in underground coal mines (6). STOP can help to define the material handling advantages of alternative support technologies that use lighter weight materials or systems that can be installed with the aid of mechanical assist. The use of these support technologies can significantly reduce material handling injuries.

PROGRAM ARCHITECTURE

The program is a windows-based architecture. The **Main Menu** allows the user to control the flow through the program if desired. This window is always shown, and can be accessed through each of the primary program segments. The main menu contains these six modules:

File – The *File* window contains file management subroutines that allows the user to create new files, open and close existing files, and exit from the program. The File Menu also allows the user to set the path for storage of several photographs that are incorporated into the program for visual display of the support performance.

Information – The *Information* window can be thought of as a general information center. The various support technologies are categorized in six groups: (1) conventional wood (crib) supports, (2) engineered timber supports, (3) conventional concrete crib supports, (4) yieldable concrete supports, (5) steel supports, and (6) additional supports. From this list and the embedded sub menus, the user can select a specific support and learn more about the support through several other program buttons. *Keypoints* provides a description of the support, design and installation considerations, performance characteristics of the support, and manufacturer or supplier contact information. *Performance* displays the loading profile of the support with photographs that depict the deformation and associated support loading. *NIOSH Testing Laboratory* describes the Mine Roof Simulator and makes reference to the safety performance testing protocols through which the performance characteristics of the support were determined. *Reference/Bibliography* contains relevant reference material pertaining to the selected support system.

Design Criteria – The *Design Criteria* window is where the load and convergence design criteria for the support system are formulated. The requirement is to define the required support load density in terms of tons of support capacity per linear ft of entry advance and at what convergence this support capability is to be provided. There are 4 different ways to establish these design criteria in the program: (1) ground reaction curve, (2) detached block, (3) current support system, and (4) arbitrary criteria.
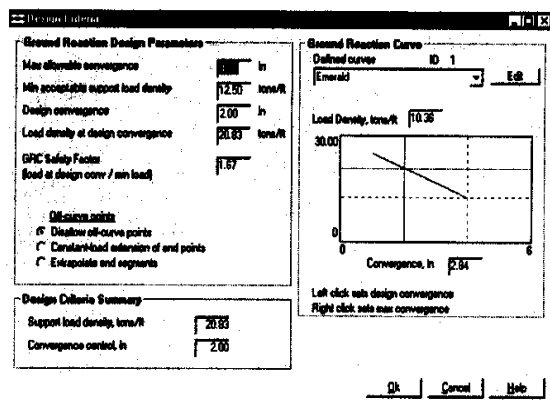

Figure 1. Window for establishing design criteria based on a ground reaction curve

1. The *Ground Reaction Curve* (figure 1) allows the user to define the support load density and convergence criteria from in mine measurements of the ground behavior (convergence) associated with various support systems (*4, 5*). Essentially, the ground reaction concept implies that the convergence in the mine entry is controlled by the magnitude of the support resistance. Generally, the convergence decreases with increasing support load density. Hence, if measurements of convergence are made with two or more support systems of varying stiffness, then a ground reaction curve can be

established for that particular mine. The user can define a ground reaction curve or use one from the data base established from various mine sites which is maintained in the program. Once a ground reaction curve is defined, the program will determine the required spacing for a particular support system that will provide the support load density consistent with the ground reaction curve at a particular convergence.

2. The *Detached Block* window is shown in figure 2. The support load density requirements are established by calculating the weight of a detached block of roof rock above the mine entry. The failure height can be input by the user or estimated from the quality of the roof rock (Coal Mine Roof Rating) using an approximation developed by Unal (*7*). The volume of the block is also influenced by the shape of the failure. Options include either an arch or a vertical shear failure at the pillar boundaries. Two options are available for determining the convergence criteria. If ground reaction information is available, this information can be used to help define the convergence criteria. In terms of the ground reaction curve, there is a critical convergence where failure of the roof occurs. This could be used to define the convergence criteria for the detached block, the idea being that the support should put the roof rock mass into equilibrium before the critical convergence is reached. If this option is selected, the convergence is defaulted to the maximum convergence on the ground reaction curve, but the user can change this input if desired. In the absence of ground reaction information, the user can simply input a convergence criteria (allowable displacement before roof weight is supported in equilibrium).
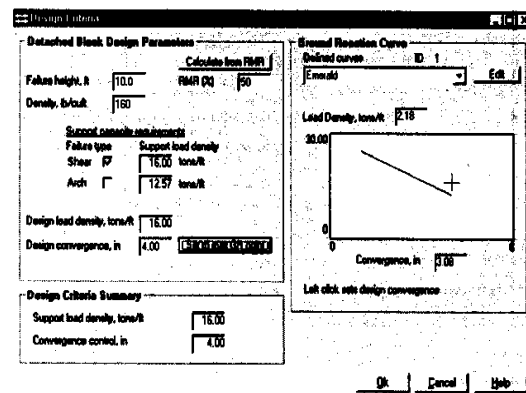

Figure 2. Window to establish design criteria based on detached roof block

3. The *Current Support System* allows the user to define the design requirements based on the performance of the current support system (figure 3). There are two options available. One, if a ground reaction curve is available, then the program will determine where the current support system falls on the ground reaction curve, and set the support load density and convergence requirements to that point. For the second

option, the user must define an allowable convergence which should be based on some in mine measurements. The support capacity and resulting load density for the support spacing will be calculated from the load-displacement profile for the support as determined from tests in the Mine Roof Simulator or other laboratory data.
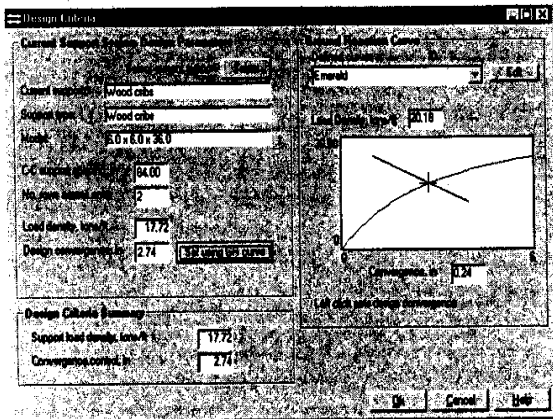

Figure 3. Window to establish design criteria based on current roof support system

4. *Arbitrary Criteria* simply allows the user to set the support load density and convergence criteria to any arbitrary set of values.

Support Evaluation -- The *Support Evaluation* module is the heart of the support design process. Any of a variety of support systems contained in the program data base can be selected for design and analysis (figure 4). Selecting the *Design* feature calls a subroutine which allows the user to control relevant design parameters and/or pick from the available design (models) for a particular support type (figure 5). The user must also input the number of rows to be used in the support placement. The program will then calculate the required spacing of the supports to achieve the desired support load density at the designated convergence, or the user can select a support spacing and the achieved convergence will then be calculated for the user-defined support installation. An optimization algorithm is also included in which the program will determine the support design or model which most closely matches the design criteria (support load density at designated convergence). Also included in the *Support Evaluation* module are analyses of the installed support costs and the material handling requirements for the support.
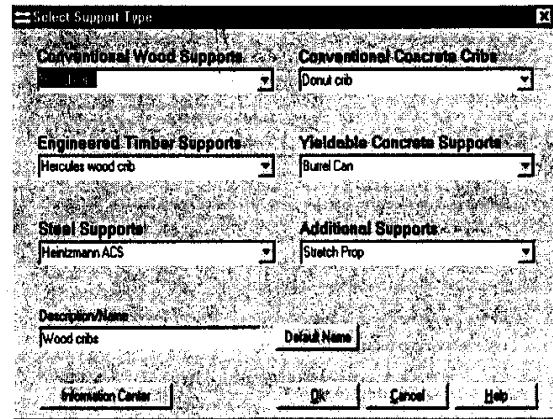

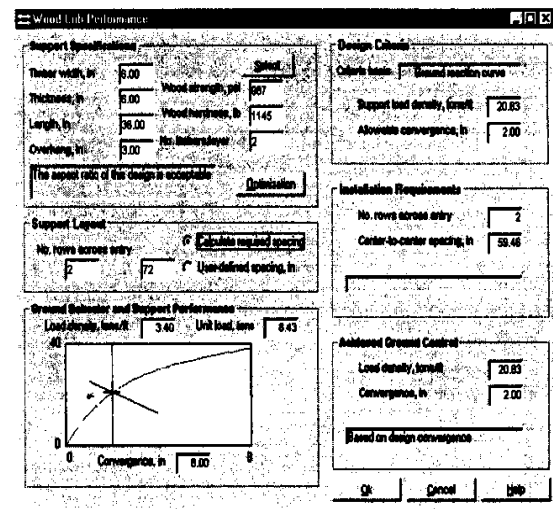Figure 4. Window for selecting support types for design and analysis

Figure 5. Window for designing the support system and determining the installation requirements to achieve the design criteria objectives

Comparison – The *Comparison* module provides comparison of the selected and designed supported systems. There are three windows in the Comparison module: (1) Comparison, (2) Summary, and (3) Plot. The *Comparison* window describes the support layout (number of rows and support spacing) and has a tabular listing of various design parameters for each support system. The parameters are grouped into categories: (1) ground control, (2) costs, and (3) material handling. The user can pick any one of the selected support systems to use a baseline system for comparison purposes. The *Summary* window summarizes the support design parameters for each support system. The *Plot* window allows the user to plot the support performance (unit support load or support load density) as a function of convergence and graphically compare the various support systems as shown in the example in figure 6. Ground reaction data can also be displayed on the plots to show the convergence control provided by the various support systems relative to the ground reaction curve.
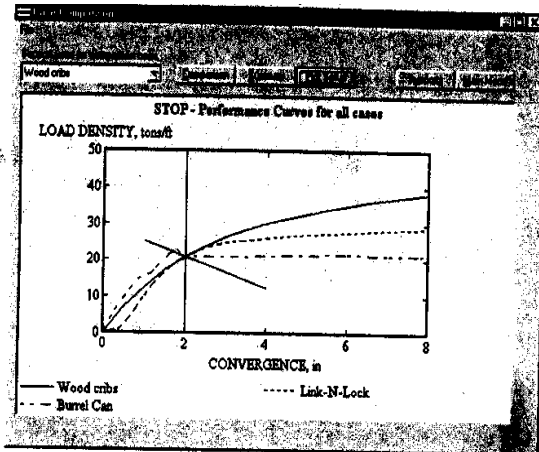
Figure 6. Graphical analysis of selected support systems showing support load density as a function of convergence

Help – A context-sensitive help file is available to facilitate the operation of the program and interpretation of the results. The Help file can be called from each window or from the main menu.

Using the Program

Generally, the program control guides the user through a logical sequence of operations to facilitate the design and implementation of a roof support system. Figure 7 is a diagram of this program flow.

The **Information Center** is shown on start up. Here, the user can explore the various support technologies that are available, examine relevant design and installation

considerations, and observe the failure stages of the various support structures. The *Next* button transfers control to the **Design Criteria** module to a window where the user must select the basis for establishing the design criteria, choosing one of the following options: (1) detached block, (2) ground reaction curve, (3) current support system, or (4) arbitrary criteria. Control is then transferred to the appropriate window for the chosen design criteria and the user then defines the support load density and convergence design criteria in that window. Once the design criteria are established, control is transferred to the **Select Supports** window. It is here where the user picks the supports to evaluate. There are several options available: (1) *Add* allows the user to select a new support, (2) *Delete* to delete a support from consideration, (3) *Duplicate* to duplicate a support, which can be helpful when you want to reevaluate a support design with a few minor changes, and (4) *Rename* to simply rename the support.

After a support type is selected, control is transferred to a window where the user can define the appropriate support design parameters. Once the user defines the support design, the program calculates two outputs: (1) *Achieved Ground Control* where the convergence control provided by the support system and the support load density are displayed and (2) *Installation Requirements* where the number of rows and required support spacing are provided. For most supports, under the **Support Specifications**, there is also an *Optimization* button. Clicking on the *Optimization* button causes the program to transfer to an optimization window where the user can select a support spacing and number of rows and the program will calculate the support model or design that most closely matches the required convergence and support load density previously established in the design criteria. The optimization algorithm depends on
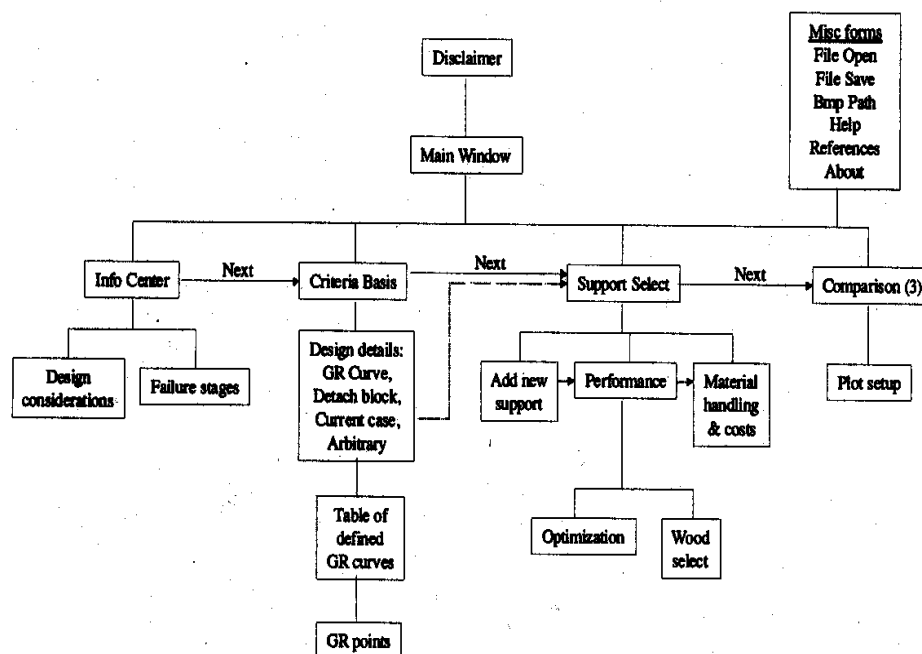

Figure 7. Flow diagram showing program control.

which spacing option was selected in the support specifications window. If "Calculate the required spacing" option was selected, the optimization routine will select a support design that will meet the design criteria at less than the specified maximum spacing. If the "User-defined spacing" option is selected, then the program will determine a support design that will meet the load density requirement at a convergence less than the design convergence.

Once the support system is defined and the installation requirements (number of rows and spacing) are determined, then control is transferred to the materials handling window where the support costs and material handling requirements can be defined and examined. A set of default values are included in the program that are considered to be representative of the various support technologies at the present time, however, the program allows the user to modify any of these parameters. In particular the cost parameters may be mine specific and time dependent to some degree. These default values will be updated periodically on the web site version, but the user should contact the support manufacturers to receive the latest cost information. Finally, the *Next* button transfers control to the **Comparison** module where the various support systems can be compared to one another.
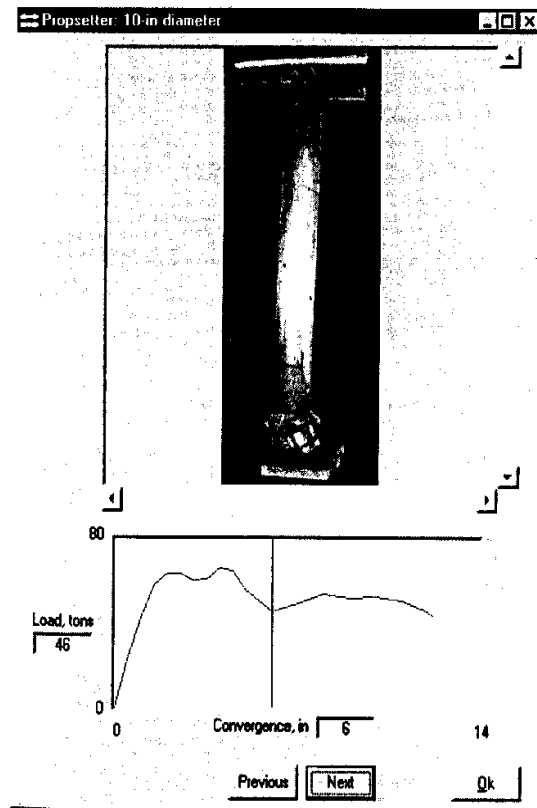

Figure 8. An example of the loading profile display available in the Information Center

EXAMPLE APPLICATIONS OF STOP

Examining the Loading Profile of a Support System

In the *Information Center* of STOP, photographs of each support during its loading phases are shown when the *Performance* button is clicked. The load-displacement curve for the support is shown with a line to designate the displacement that corresponds to the photo in the window. Photos are typically shown at 2-in increments in support displacement. An example for the Propsetter support is shown below (figure 8).

Optimizing the Use of Conventional Wood Cribs

Historically, conventional wood cribs have been used extensively for secondary roof support. A common support system is a double row of 4-point cribs constructed from 5x6 in (cross-sectional dimensions), 30-in-long, mixed hardwood timbers. STOP can be used to evaluate alternative designs and show that 9-point cribbing can be more cost-effective. The procedure to conduct such an analysis would be as follows:

1. Review the design information on conventional wood cribs in the *Information Center*.

2. Choose *Current Support Systems* for the basis for selecting the design criteria. Enter the entry width and height. Since no supports have been defined yet, the program will transfer control to the *Select Supports* window. Clicking on the *Add* option will transfer control to the support menu where wood cribs can be selected.

3. Control will be transferred to the *Wood Crib Specifications* window where the wood crib parameters are defined. Enter the wood crib specifications (timber width, timber thickness, timber length) and select the mixed hardwood species to establish the wood strength. Input the number of timbers per layer. After confirming the support design, *Ok* transfers control to the *Select Supports* window.

4. Hitting *Ok* here then transfers control to the *Design Criteria* window, where the current wood crib design is featured. You will now need to enter a value for the spacing of the supports, number of rows, and enter a convergence to establish the support load density design criteria. In this example, a spacing of 81 inches for a double row of cribs and a convergence of 4.0 inches was chosen.

5. When control is transferred back to the *Select Supports* window, the user has the option to examine the support material handling and costs (by clicking on the *Design and Costs* button).

6. After reviewing the material handling and cost information, the control will be transferred back to the *Select Supports* window, where the alternative support designs are entered and evaluated accordingly. One way to accomplish this is to duplicate the current support and simply change the number

of timbers per layer from 2 to 3 and the number of rows from 2 to 1. The program will then calculate the required spacing of single row of 9-point cribs that will provide the same load density as that of the double row of 4-point cribs.

Figure 9 documents the result of one such analysis, comparing the installed cost of a double row of 4-point cribs on an 81-in center-to-center spacing with that of single row of 9-point cribs on a 92-in spacing. Both support systems, with cribs constructed from 5x6x30 in mixed hardwood timbers, provide 10.5 tons per ft of support capacity at 4 in of convergence. Also included in this analysis is a double row of 4-point cribs constructed from all oak timbers instead of mixed hardwoods. Note that in this analysis, the narrow side of the timber (5-in side) was placed down to establish the interlayer contact.
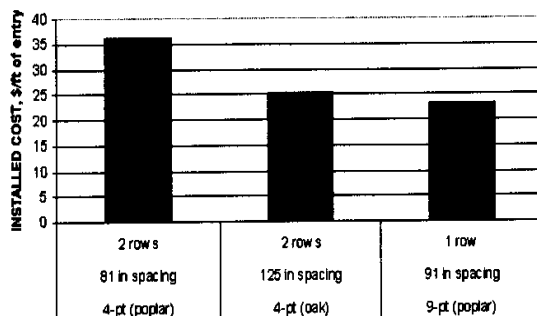

Figure 9. Comparing the installation costs of various wood crib designs (5x6x30 in timbers with 5-in side placed down)

Figure 10 illustrates the same comparison except that the cribs are constructed with the wide-side-down (6-in side) instead of the narrow side down (5-in side) as was done in the previous example. The results clearly show the benefits of maximizing the support capacity by increasing the contact area with the wide-side-down construction.
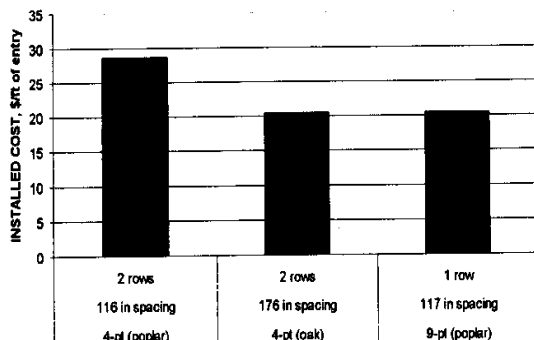

Figure 10. Same analysis as shown in figure 9 except the wide side of timber (6-in side) was placed down to establish the interlayer contact among adjacent timbers

Replacing Conventional Wood Cribbing with Engineered Timber Supports

In recent years, numerous alternative timber supports have been developed. These supports are engineered to provide improved loading characteristics compared to conventional wood cribbing. For this example, the goal is to replace a conventional wood crib design with engineered timber supports and provide equivalent support capability in terms of support load density at a specific convergence. The procedure for designing these engineered timber support applications is basically the same as in the previous example except the alternative supports are chosen for analysis instead of conventional wood crib designs.

The baseline case for this example is the same as that chosen in the previous example: double row of 4-point, mixed-hardwood cribs on a 116-in spacing providing 10.52 tons per ft of support capacity at 4 in of convergence. The alternative supports chosen for this example are: (1) 24-in Link-N-Lock, (2) 30-in Link-N-Lock, (3) Hercules HM-9(308) crib, and (4) 30-in Tri-Log crib. Figure 11 shows the installed support cost per ft of entry for support systems designed by the STOP to provide equivalent support loading to that of the baseline conventional wood crib support system. The installation requirements are also shown. As seen in figure 11, all four of the engineered timber support systems are able to reduce the installed support cost considerably without sacrificing support capability.
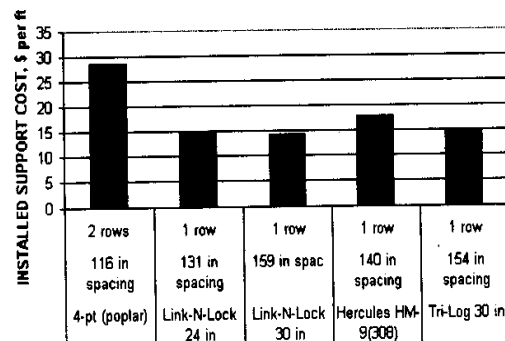

Figure 11. Evaluation of engineered timber support systems as a replacement to conventional wood cribbing

Increasing the Support Load Density to Reduce Entry Convergence

The objective of increasing the support load density is to improve ground control by allowing less roof movement to occur. If the ground reaction at a particular mine is known, then support systems can be designed to provide any measure of convergence desired. The following example (figure 12) is based on a ground reaction curve selected from the program's data base. Using this curve, the convergence is reduced from 4 in, achieved with two rows of conventional 4-point, mixed-hardwood cribs on a 97-in spacing, to 2 in with alternative support designs.
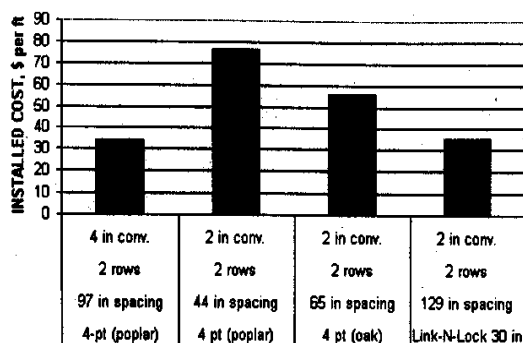
Figure 12. Analysis of support system options when the convergence requirement is reduced from 4 to 2 in.

1. Review the design information on the various support technologies in the *Information Center*.

2. Choose *Ground Reaction Curve* for the basis for selecting the design criteria. In the Ground Reaction form, the Emerald ground reaction curve is chosen. Input 4.0 in for the design convergence and the program will determine the required support load density that is consistent with the ground reaction curve. In this case, it is 10.50 tons per ft.

3. Control will then be transferred to the *Support Selection* window. Wood cribs are chosen for the support type.

4. Control will then be transferred to the *Wood Crib Performance* window, where parameters for a 4-point wood crib are defined. The program will then determine the installation requirements for this crib design. The program proceeds to the *Costs* window. The default settings for the wood crib are reviewed and modified as needed. The program then computes an installed cost per ft of entry for this support design.

5. Control is then transferred to the *Comparison* module where the performance parameters for this support system can be reviewed.

6. The *Comparison* window is then closed by transferring control back to the *Main Menu*. Here the *Design Criteria* is activated and the *Ground Reaction Curve* criteria is again selected. The Emerald curve is again chosen. Now the design convergence is changed to 2.0 in.

7. Control will then be transferred back to the *Support Selection* window. Now the various alterative support technologies can be selected and designed in the respective *Performance* windows.

8. When the support designs are completed, the *Comparison* window will now show the baseline wood crib system at 4 in of convergence and the alternative support design performance measures at 2 in of convergence.

Replacing Timber Supports with Other Alternatives

There are several alternatives to timber supports. The STOP can be used to evaluate these various alternatives and make comparisons based on equivalent support capability or show the advantages of alternative placement strategies with superior roof support systems. The following example will show how these alternative support technologies can be designed relative to the current roof support system using available ground reaction data. The process begins by selecting the *Current Support System* for design basis. For this example, the current roof support system is a double row of 4-point wood cribs. Hence, the user selects wood cribs as the support type and then enters the appropriate data in the *Wood Crib Specifications* form to define a 4-point crib constructed from 6x6x36 in oak timbers. The center-to-center support spacing is entered (108 in in this case) and the number of support rows (2 in this case). The design convergence and support load density are determined by

Table 1. Comparison of alternative support technologies as replacements for conventional wood cribbing.

Design Requirements: Support Load Density =15.25 tons/ft Convergence = 3.4 in					
Support type	Design specifics	Installation requirements		Achieved convergence control, in	Achieved support load density, tons/ft
		No. rows	Spacing		
Wood Cribs	4-pt (6x6x36 in oak timbers)	2	108	3.4	15.25
Pumpable Crib	30 in	1	116	0.9[1]	25.23
ACS	Pizza Headplate	2	133	2.6[1]	19.74
The Can	24in diameter	2	138	3.4	15.25
Stretch Prop	timber ft/hd boards	3	61	3.4	15.25

[1]Since this particular support begins to shed load prior to the design convergence of 3.4 in, the peak support loading was used to determine the support spacing and achieved support load density which occurs below the design convergence. This is the preferred application design for these supports since the support capacity at the peak loading would control the convergence prior to yielding.

Table 2. Support systems determined by the optimization routine for user -define support installation parameters.

Design Requirements: Support Load Density = 16.67 tons/ft Convergence = 3.0 in					
Support type	Optimized design	User specified installation requirements		Achieved convergence control, in	Achieved support load density, tons/ft
		No. rows	Spacing		
Wood Cribs	9-pt (5x5x30 in timbers)	2	96	2.8	17.6
Link-N-Lock	36 in	1	96	2.6	18.5
Tri-Log Cribs	30-in standard	2	96	1.6	22.5
Propsetter	10-in diameter	2	96	2.6	18.4
The Can	24 in	2	96	1.6	22.5

clicking on the *Set using GR curve*, where it is shown that the current support system intersects the chosen ground reaction curve at 3.34 in of displacement and provides a support load density of 15.25 tons/foot. Table 1 compares several alternative support systems that provide equivalent or improved support capability.

Using the Optimization Routines to Select the Best Support Design

The previous examples have shown how STOP will determine the required support spacing that is needed for a user-specified support design. The optimization routines allow the user to specify a support spacing and number of rows of support elements, and the program will determine which support design best fits the load and convergence design criteria. For the example shown in table 2, the design criteria of 16.67 tons per ft of entry at 3 in of convergence was established from a Ground Reaction Curve chosen from the program data base. Then various support types are selected for evaluation. When the *Optimization* button in the *Performance* form is selected, the user will define the installation requirements (number of rows and support spacing) and the program will determine the support model which most closely matches the design criteria (16.67 tons/ft at 3 in of convergence in this case). Since the installation spacing and number of rows are specified, the achieved convergence will vary depending on the support type chosen. Table 2 documents some examples of optimized supports as determined by the STOP.

Evaluating Material Handling Aspects of Support Design

Surveillance data shows that material handling injuries are common in support construction, causing several thousand lost work days each year. Hence, part of the support selection process should be the material handling requirements. Figure 13 is an example of data derived from STOP for four support systems: (1) Pumbable Crib, (2) Alternative Crib Support or

ACS, (3), Propsetter, and (4) conventional 4-point crib. As seen from this analysis (figures 13a-13c), there are significant material handling advantages in using the alterative support technologies compared to conventional wood cribbing.
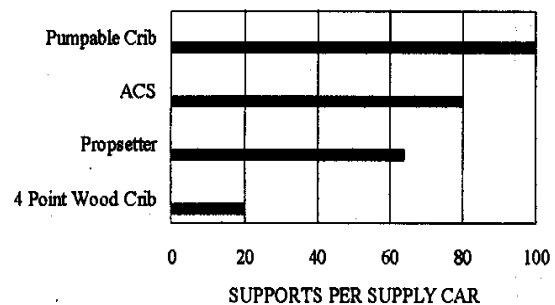

Figure 13a. Comparing the number of supports per supply car for conventional wood cribbing and three alternative support technologies
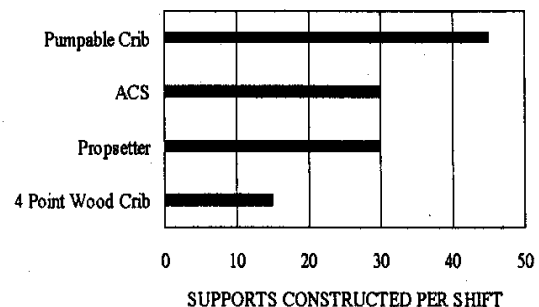

Figure 13b. Comparing the supports constructed per shift for conventional wood cribbing and three alternative support systems
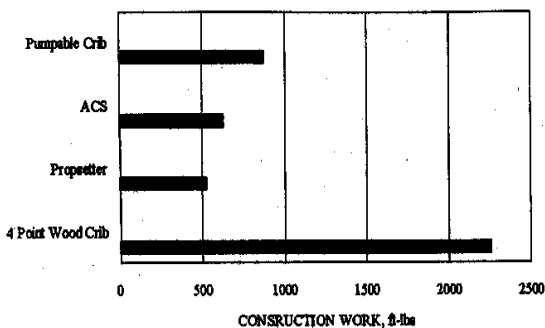
Figure 13c. Comparing the construction work for conventional wood cribbing and three alternative support systems

CONCLUSIONS

Historically, wood cribs have been used as secondary roof support in underground mines. The Wood Crib Performance Model was developed by the U.S. Bureau of Mines in 1994 to provide an engineering foundation for the design and applications of these supports. In the past few years, many new support technologies have been developed by various roof support manufacturers. These innovative support technologies provide superior roof support and reduced material handling requirements in many cases. However, each has its own performance characteristic, hence they all need to be employed differently in order to provide equivalent roof support.

STOP was developed to provide a more comprehensive support design program than that provided by the old Wood Crib Performance Model. Not only does STOP include all of the new support technologies that have been developed, it also allows for application of a new design methodology based on a measured ground reaction curve at a particular mine site. Also included in STOP are a comprehensive material handling assessment and cost evaluation for each support system. STOP is a window's-based program that is user-friendly and very flexible to provide engineering solutions for various secondary support applications.

STOP can be used to determine the installation requirements for an alternative support technology that will provide equivalent support as compared to the mine's current support system or an installation that will provide a specified support load density at a designated roof convergence. The optimization routines in the program will select the most efficient support design for the user-specified criteria.

STOP utilizes performance data developed by NIOSH through safety performance testing in the unique Mine Roof Simulator load frame. Each of these support systems have been evaluated through a rigorous testing protocol that simulates in mine service conditions. Photographs of the support condition at various stages of loading are also included in STOP. These photographs help to provide an appreciation for the limitations

of the support, and can be used to assess the general loading conditions when these profiles are observed underground.

STOP can provide some much needed engineering to secondary roof support. This can be very helpful when petitioning MSHA for approval to use an alternative support technology or making changes in application such as increasing the support spacing. By proper engineering of the support relative to the ground reaction, convergence can be controlled to a predetermined level. This will allow an operator to optimize the support application and provide a margin of safety in roof stability that will reduce the likelihood of roof failure without the need for excessive roof support. Likewise, this will remove the uncertainty in the support design and prevent the application of inadequate support that can lead to roof falls. Finally, STOP will allow mine operators to fully consider the material handling aspects of support design in the selection process, and by doing so reduce the incidence and severity of material handling injuries.

REFERENCES

1. Mark C. Analysis of Longwall Pillar Stability (ALPS): An Update. In proceedings of the Workshop on Coal Pillar Mechanics and Design. U.S. Department of Interior, Bureau of Mines, Information Circular 9315, 1992, pp. 238-249.
2. Mark C, Chase FE. Analysis of Retreat Mining Pillar Stability. In proceedings of the New Technology for Ground Control in Retreat Mining. U.S. Department of Health and Human Services, Center for Disease Control, National Institute for Occupational Safety and Health, Information Circular 9446, 1997, pp. 17-35.
3. Barczak TM, Gearhart DF. Engineering Methods for the Design and Employment of Wood Cribs. U.S. Department of Interior, Bureau of Mines, Information Circular 9361, 1993, 34 pp.
4. Mucho TP, Barczak TM, Dolinar DR, Bryja J, Bower J. Design Methodology for Standing Roof Support in Longwall Tailgates. In Proceeding of the 18th International Conference on Ground Control in Mining, 1999, pp. 136-148..
5. Barczak TM, Mucho TP, Dolinar DR, Bryja J, Bower J. Longwall Tailgate Support, Consideration, Design, and Experience. In Proceedings of the Longwall USA, 1999, pp. 79-105. 6. MSHA. Data from the Mine Safety and Health Administration computerized data base on mine injury and accidents. Accessible through the MSHA web site.
7. Unal E. Empirical Approach to Calculate Rock Loads in Coal Mine Roadways. In Proceedings of the 5th Annual Conference on Ground Control in Mining. WV University, 1986, pp. 234-241.